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2003 MiniBoone ^{7}Be, Tritium, and Airborne Radioactivity Assessment

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Introduction

In December of 2002 it was noticed that an icicle had formed on the outside of the MiniBoone exhaust housing at MI-10. The icicle was submitted for nuclide analysis and it was found to have a concentration of 1040 pCi/ml of tritium. Later in the month on a cold day the 100 cfm fan at MI-10 was tripping off the permit for MiniBoone, as it was unable to maintain the required 100 cfm airflow. It was determined that the exhaust filter system had become laden with ice and water, and that a louver inside the system had closed slightly. The exhaust filter and the exhaust pre-filter were removed and replaced with new ones, and the louver was re-adjusted. 100,000 counts per minute were noted on contact with the center of the exhaust filter, and 20,000 counts per minute were noted on the pre-filter using a Bicron Analyst. These filters have only one layer of filter material; there is no upstream and downstream side. The filters were stored over the weekend to remove the effects of radon daughter build up on the filters, since radon daughters will normally decay away after several hours. On December 9, 2002, the filters were re-checked and the count rates unexpectedly had not dropped at all. It was obvious that radon daughters were not the source of the activity on the filters. A sample was taken from the pre-filter and submitted for analysis to determine the radionuclide present. The analysis indicated that a significant amount of ^{7}Be was present. These results prompted an investigation of the ^{7}Be levels throughout MiniBoone.

Airborne ^{7}Be most likely accumulated on the filters over a period of several weeks, leading to the large measured values of activity. However, when the total volume of air sampled is taken into account, it was concluded that the ^{7}Be airborne radioactivity concentrations did not exceed regulatory limits. It was also determined that the radiological hazard to personnel of ^{7}Be found in the enclosure and ^{3}H found in the icicle were insignificant.

The radiological concerns of ^{7}Be outweigh the non-radiological, chemically-related concerns of elemental beryllium as a personnel hazard with respect to the Fermilab Environmental Safety and Health Manual (FESHM) release criteria.

Portable field instruments such as friskers are unable to detect ^{7}Be contamination at levels less than about 45,000 pCi/100 cm^2. This level of activity results in an estimated count rate on the frisker of about twice background assuming ^{7}Be is the only nuclide present. To correlate this level of activity to an estimated radiological hazard to personnel, the Committed Effective Dose Equivalent (CEDE) resulting from a hypothetical ingestion of this amount of ^{7}Be is about 6 μrem.

Discussion and Methodology

Several samples were taken throughout the MI-12 Service Building, and in grid patterns within the MI-12B enclosure. Within the enclosure, wipes were taken in several locations, concentrating on the downstream end of MI-12B as it was thought the source of the ^{7}Be was from the enclosed target station at the downstream end. Only one location, a ledge immediately below the doors to the target station, where wipes were taken in the open areas of the MI-12B enclosure was found to contain a measurable concentration of ^{7}Be. This ledge is on the downstream end of MI-12B and is readily accessible to personnel who access the enclosure. Wipes were also taken inside the ports for the air-cooling unit of the target cooling filter housing. The upstream port contained a significant amount of ^{7}Be whereas the downstream port did not. The stack monitors in the MI-12 Service Building continuously sample the MI-12B enclosure air just upstream of the target station, and the MI-12 Service Building air. There is also a stack monitor at the upstream location of MI-12A, which continuously samples the air before it is sampled and exhausted to the environment. Since ^{7}Be is a particulate, it would be captured by a small cylindrical filter in the intake line before the air is counted in the stack monitor. These filters were removed and analyzed for ^{7}Be at the FNAL Radionuclide Analysis Facility (RAF). Considerable amounts of ^{7}Be activity were found on these filters; however when the large volume of air is taken into account the estimated airborne radioactivity concentrations were low compared to regulatory limits.

From July through September of 2003 several additional wipe surveys were taken in the MI-12B enclosure. It appeared to the investigators that the distribution of ^{7}Be was fairly uniform, taking into account variations in wipe taking technique and amount of material picked up on the wipes. Activity levels in general were on the order of 10,000 pCi/100cm^{2} of ^{7}Be, except in August two wipes were 35,800 and 65,900 pCi/100cm^{2} near the target box wall on the floor.

An illustration of the MiniBoone area along with a depiction of where the samples were taken in January of 2003 is included as Attachment 1.

It was recognized that ^{7}Be with its 10% gamma branching ratio, would not be easily detectable at low levels, nor could it be differentiated from other known enclosure contaminants on wipes measured within a few hours of beam shutdown. It was also recognized that ^{7}Be potentially presents a non-radiological chemical hazard to personnel as elemental beryllium, at high concentration levels. It was determined that the radiological considerations of ^{7}Be take precedence before the non-radiological concerns. A comparison of the non-radiological beryllium contamination equipment release criterion to the corresponding estimated radiological ^{7}Be activity level is included in a later section of this paper.

Evaluations of the radiological hazard to personnel from the tritium and ^{7}Be follow.

Evaluation of the Radiological Hazard from Tritium

The icicle that had formed on the outside of the MI-12A exhaust filter housing was found to have a concentration of 1040 pCi/ml of ^{3}H. If a person hypothetically ingested 8 ounces of this icicle water, an extremely implausible worst-case scenario, the resulting Committed Effective Dose Equivalent (CEDE) is about 16 μrem. Therefore the radiological hazard from the concentration of tritium in this icicle was deemed insignificant.

Evaluation the Radiological Hazard from ^{7}Be Contamination

To provide a relative evaluation of the radiological hazard from ^{7}Be contamination, it was assumed that the amount of ^{7}Be present on a 100 cm^2 wipe was ingested. The reader is cautioned that this scenario is highly improbable.

Wipe #14 was the first wipe seen with ^{7}Be activity in January 2003. It was taken from the ledge in MI-12B and found to have a ^{7}Be concentration of 1390 pCi. If a person hypothetically ingested that amount of ^{7}Be on this 100 cm^2 wipe, the resulting CEDE is about 0.18 μrem.

Several follow-up wipe surveys of the MI-12B enclosure were conducted when opportunities arose beginning in July 2003. The most extensive survey was conducted on July 11, 2003, when a total of 34 wipes were taken throughout the enclosure. The distribution of the ^{7}Be appears to be fairly uniform, for all practical purposes the activity was deemed to be about 10,000 pCi/wipe. Perceived variations in the concentrations found should be tempered with the recognition that there are slight variations in the amount of material adhering to each wipe and in wipe technique.

Calculations of the CEDE for varying amounts of ^{7}Be activity are plotted in Attachment 2, "Committed Effective Dose Equivalent (CEDE) from Hypothetical Ingestion of ^{7}Be (log/log scale)." In this chart it is seen that at the activity level of 10,000 pCi/wipe the CEDE is about 1 μrem assuming the amount of ^{7}Be on the wipe is ingested. The amounts of ^{7}Be activity that correspond to a CEDE of 100 mrem, 300 mrem, 1500 mrem, and 5000 mrem are also shown.

For a person to ingest the amount of ^{7}Be that results in a CEDE of 5 rem per year, they would need to ingest about 3.9×10^{10} pCi of ^{7}Be. The amount in grams for this activity is estimated to be about 0.11 μgrams, which is about half of the FESHM 5052.5 release to the general public limit of 0.2 μg for elemental beryllium surface contamination. A "Comparison of the FESHM 5052.5 Beryllium Surface Contamination Release Criterion to the Corresponding ^{7}Be Activity Level" follows.

Comparison of the FESHM 5052.5 Beryllium Surface Contamination Release Criterion to the Corresponding ^{7}Be Activity Level.

FESHM 5052.5 states that 0.2 μg/100cm^2 is the surface contamination limit for release of beryllium contaminated equipment to the general public. The purpose of this comparison is to estimate the corresponding count rate on a frisker for ^{7}Be contamination at the FESHM release criterion. Personnel accessing the enclosure may come in contact with ^{7}Be contamination, and from a non-radiological standpoint there was concern that there could be a chemical hazard from exposure to beryllium as the isotope ^{7}Be.

Assumptions:

1. All activity measured on a 100-cm^2 wipe is due to ^{7}Be.

Calculation:

0.2×10^{-6} grams of ^{7}Be

$A=\lambda N$, where

A=Activity in Becquerels
λ=Decay constant for ^{7}Be
N=Number of atoms of ^{7}Be

Determine N, then solve for A

$$N = \frac{6.02x10^{23}\,atoms/mole}{7\,grams/mole} x0.2 \times 10^{-6} \text{ grams} = 1.72 \times 10^{16} \text{ atoms}$$

$$A = \lambda \quad x \quad N = 2.6x10^{9}\,Bq$$

or 7×10^{7} nCi of ^{7}Be.[1]

Impact of ^{7}Be in the MI-12A and MI-12B Enclosures

Since ^{7}Be is difficult to detect at low levels with portable field instruments such as the frisker or an Analyst, another field instrument was needed. The Fermilab RPCF personnel took a Bicron Analyst from their inventory and modified it to function as a single-channel-analyzer with the energy window centered on the 477 keV peak of ^{7}Be. The background rate for this instrument is nominally about 76 cpm. With the background taken to be about 76 cpm, the MDA level of this instrument is about 152 cpm (twice background). At 152 cpm, the activity of ^{7}Be is about 17.5 nCi. (See Fred Krueger's paper/memo). Field measurements with the modified Analyst must be interpreted with caution. Other isotopes if present may cause interference in the 477 keV window, from Compton scattering and the proximity of the 511 keV peak. To compare to a frisker, a frisker at twice background is about 100 cpm which corresponds to about 45 nCi if we assume all of the activity is from ^{7}Be with no other isotopes present. With either instrument, the MDA is technically above the FRCM contamination limit of 0.45 nCi, however if the hazard from ^{7}Be ingestion is evaluated with a CEDE approach, the radiological hazard is deemed insignificant.

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[1] In this discussion of the comparision of the chemical hazard from the beryllium element with the radiological one due to the ^{7}Be, the production of other isotopes aside from ^{7}Be are being produced should also be considered. For the spallation reactions of concern, the cross sections for the production of the non-radioctive isotopes of Be, though not readily available are extremely unlikely to differ from that associated with the production of ^{7}Be by more than, say, a factor of 2. Aside from those two having half-lives too short to matter, one needs to be concerned with two additional isotopes; ^{9}Be (stable) and ^{10}Be (half-life = 1.5×10^{6} years, nearly stable). Thus, applying a factor of 2 for the additional *nonradioactive* isotopes present that would contribute to the *chemical* toxicity and a factor of 2 for possible cross section differences, in the *worst case*, Thus, at the industrial hygiene standard of 0.2 micrograms of total Be, one would expect at least 2×10^{7} nCi of ^{7}Be, still a very large value on a wipe.

It is impractical to rely upon the modified Analyst to perform personnel frisks, as only one is available and it is not intended to be available to radiation workers. Interpretation of the readings must be made by knowledgeable radiation safety personnel. Radiation safety personnel would need to be present at the enclosure exit every time an access is made. Nor is the efficacy of the Analyst in determining whether a person is contaminated known completely because the geometry of the detector is different from a frisker. The MDA of the Analyst was determined essentially by assuming the contamination is comparable to a point source, and the ability of the detector to provide accurate readings of contamination spread over a larger area is not known. The only other instrument available is the standard frisker.

If a person hypothetically ingested 17.5 nCi of ^{7}Be on a 100 cm^2 wipe (at the MDA of the modified Analyst), this would correspond to a CEDE of about 2 μrem, compared to about 6 μrem from a 45 nCi wipe (at the MDA of a frisker). See Attachment 2 for a plot of the CEDE with a hypothetical ingestion of the amount of ^{7}Be taken on a 100 cm^2 wipe.

Current controls in place at MI-12A and MI-12B include the requirement that protective clothing be worn. Workers are instructed to remove their shoe covers and step over the door jam of the door between the MI-12 Service Building and the stairwell to Enclosure MI-12B. The door jam is taken to be a dividing line between the clean area and the potentially contaminated area. The shoe covers are presumed to be contaminated with ^{7}Be, and are not frisked. They are thrown into a radioactive waste bag near the frisker. The workers then frisk themselves normally before removing their gloves and coveralls or lab coats. Radiation Safety personnel assist workers when they exit the tunnel to check for contamination on themselves, their tools, and items removed from the tunnel with the modified Analyst as necessary.

Workers who frisk themselves and do not detect counts greater than 100 cpm above background could potentially miss detecting 45 nCi/100 cm^2 of ^{7}Be contamination on themselves (at the MDA of a frisker). Readers are reminded that detecting counts on protective clothing does not constitute a contaminated worker. Only counts detected on skin and personal clothing are of concern. Workers who use a frisker and fail to detect contamination at levels below the frisker MDA (100 cpm which corresponds to about 45 nCi) on their skin or clothing, and then hypothetically ingest the contamination, could potentially receive a CEDE of about 6 μrem (at the MDA of a frisker) depending on the amount actually ingested (assuming an amount of 45 nCi ^{7}Be activity on a 100 cm^2 wipe). The likelihood of this occurrence is extremely small, since the workers are required to wear protective clothing.

Currently there does not appear to be instruments commercially available for portable field use in the manner of a frisker that is able to detect 1000 dpm of ^{7}Be. It was estimated elsewhere in this paper that 0.45 nCi of ^{7}Be corresponds to about 1 cpm above background on a frisker. The FRCM specifies that 100 cpm above background is considered to be the threshold for personnel contamination, and 100 cpm corresponds to about 45 nCi of ^{7}Be whereas for most other isotopes the 1000 dpm corresponds to about 0.45 nCi. The difficulty arises because ^{7}Be has a 10% branching ratio and the efficiency of a frisker for gammas is typically taken to be 1%. The specification that 1000 dpm is the contamination limit for beta-gamma emitters, including ^{7}Be by default, does not appear to adequately consider the difficulty in detecting ^{7}Be using the same portable field instruments typically used for other isotopes.

Strict interpretation of the FRCM requires that areas are posted as contamination areas if wipes are greater than 0.45 nCi per 100 cm^2, notwithstanding the difficulty of detecting ^7Be. On past occasions, since ^7Be is difficult to detect, its presence has been inferred due to several other beta-gamma emitting isotopes that are usually present in a contamination area. These other isotopes are typically readily detected using a portable field instrument such as a frisker and thus are the determining factor in deciding whether general contamination is present. The amount of ^7Be could vary widely, but the actual amount of ^7Be present was inconsequential because the activities of the other isotopes were the deciding factor in determining if contamination existed. In contrast at MI-12A and MI-12B, the levels of ^7Be activities were determined by gamma spectral analysis, and confirmed that ^7Be was the predominant isotope present on the wipes, with much lower activities of other isotopes depending on time of decay after beam was turned off.

^{7}Be Airborne Radioactivity Evaluation

The Derived Air Concentration (DAC) for ^7Be is 9×10^{-6} $\mu Ci/cm^3$ for the "WEEKS" lung clearance class. In order to measure the concentration and resulting dose to personnel exposed to airborne ^7Be in the MI-12 Service Building and in the enclosure, an efficiency and calibration of an AMS-3 to measure ^7Be would need to be completed. Complicating this calibration are several unknowns, some of which are how the proportion of ^7Be varies over time and varying airflow patterns with other airborne radionuclides such as ^{11}C and ^{13}N. Within the tunnel, the conservative approach would be to simply monitor the count rate in the enclosure and wait until the count rates have decreased to normal background levels. Within the MI-12 Service Building, there currently is not a continuous air monitor installed that is capable of measuring ^7Be that would provide a remote read-back of the concentration. The stack monitors detect non-particulate radioactivity in air. For the stack monitor currently installed in the MI-12 Service Building, it is assumed that all the ^7Be is captured in the cylinder filter before it reaches the counting chamber (paint can) and thus is not detected or counted.

However, it may be possible to make a conservative estimate of the airborne radioactivity in the MI-12 Service Building and the MI-12B enclosure. If the air monitor is considered as a grab sampling unit, the time of air flow through the filter can be taken to be the air sampling time. Normally grab sampling is done for 10 minutes, however if we assume that the grab sampling instead occurred over several hundred hours, an estimate could be made of the airborne concentration in the enclosure and in the MI-12 Service Building. For constant activity on the filter: if the concentration of ^7Be in the air were relatively low, it would take longer to build up on the filter. If the concentration in the air were relatively high, it would take less time to build up on the filter. Thus, the calculated airborne concentration is higher for a short sampling period (e.g., 24 hours) than a longer sampling period for the same activity, resulting in a conservative calculation. Using the data from the cylinder filter and making some assumptions about the collection efficiency of the filter, estimates of the tunnel ^7Be concentration in $\mu Ci/ml$ were made for 24 hour periods of air sampling in the enclosure and the MI-12 Service Building. These are included as spreadsheet Attachments 3 and 4.

Since it is unknown how long the ^7Be was actually being produced in the tunnel i.e., whether the ^7Be was continuously produced over several weeks (most likely case) or an excursion of ^7Be occurred for one 24-hour period, a worst-case estimation can be made for the tunnel concentration assuming all the airborne ^7Be was produced in 1 day. Note that it is unlikely that any ^7Be equilibrium was reached on the filter, since typically 7 half-lives is an approximate "rule of thumb" used to infer when equilibrium occurs. After one day of air sampling the concentration of ^7Be in the enclosure is estimated to be about 2.7% the Derived Air Concentration. Since no personnel are permitted into the enclosure once beam is disabled for roughly 4 hours, or until the airborne radioactivity monitor for the enclosure reads background levels and the 1000 cfm fan has been turned on, no personnel could be exposed. See Attachment 3. A similar estimation is made for the MI-12 Service Building airborne ^7Be concentration in Attachment 4. The estimated ^7Be airborne radioactivity in the MI-12 Service Building ($2.14E^{-10}$ μCi/ml) is well below the DAC ($9E^{-6}$ μCi/ml) for ^7Be at the worst-case estimate of all the airborne ^7Be being produced in one day (24 hours). The radiological hazard to personnel from this conservative estimation of the airborne radioactivity in the MI-12 Service Building is deemed insignificant.

As the sampling time increases, up to 840 hours (5 weeks) as shown on Attachments 2 and 3, the estimated airborne radioactivity concentrations correspondingly decrease. The 840 hours maximum sampling time was arbitrary and there is no significance to this time period. The levels of ^7Be airborne radioactivity calculated after 4 or 5 weeks of sampling time are considered to be more representative of the actual conditions that prevailed in the enclosure and in MI-12 Service Building since the beam running conditions, and the conditions producing airborne ^7Be, were considered to be typical over the prior weeks.

In the current version of 10CFR835 (Vol. 63, No. 213/Wednesday, November 4, 1998), it defines an Airborne Radioactivity area as "...any area, accessible to individuals, where: (1) The concentration of airborne radioactivity, above background, exceeds or is likely to exceed the derived air concentration (DAC) values listed in appendix A or appendix C of this part; or (2) An individual present in the area without respiratory protection could receive an intake exceeding 12 DAC-hours in a week." 12 DAC-hours corresponds to an exposure equivalent of 30 mrem.

There is no need to post either the enclosure or the MI-12 Service Building as an Airborne Radioactivity area as the estimated concentration of airborne ^7Be were below the DAC limit. Within the enclosure, it is not administratively possible for personnel to be exposed to airborne radioactivity, since accesses to the enclosure are not permitted for four hours after beam shutoff or at the RSO's discretion until the airborne radioactivity monitor for MI-12B indicates that background levels of airborne radioactivity. Within the MI-12 Service Building, the estimated concentration of ^7Be was well below the DAC limit even at a worst-case assumption of all the ^7Be being produced in one day.

Accesses to MI-12B and MI-12A are administratively delayed for four hours to allow for the decay of the short-lived airborne radioactivity. The enclosure air is continuously monitored via an air monitor on the lumberjack channel RD0149. Typically the background count rate for this monitor is about 300 cpm. However, this monitor is not capable of detecting ^7Be since it is a particulate, which is trapped by the cylinder filter before the air flows to the counting chamber (paint can). Therefore, it was necessary to sample the enclosure air directly for ^7Be. Radiation Safety personnel used a High Volume Air Sampler to capture airborne particulate radioactivity, and it was determined that indeed there was airborne ^7Be. It was also verified that the current grab sampling RP Form 25 is suitable for determining the concentration of ^7Be in the air, since there was a question of whether the 10% branching ratio of ^{7}Be would adversely affect the results of the generic airborne radioactivity calculations as scripted on the form.

Recognizing that it was necessary to be able to detect ^{7}Be, an air monitor (AMS-3) was installed in the MI-12 Service Building in the summer of 2003 and is monitored on channel RD0151. This monitor samples the air in the MI-12 Service Building by collecting particulates onto a filter, in which the collected activity on the filter is counted in real time.

During the 2003 shutdown, another AMS-3 particulate monitor was installed to sample the MI-12B enclosure air. Copper sampling lines were run to the enclosure via penetrations from the MI-12 Service Building to the MI-12B enclosure below. The AMS-3 is physically located in the MI-12 Service Building. This air monitor will enable radiation safety personnel to sample the enclosure air remotely to measure the particulate airborne radioactivity. Typically after 4 hours, or when the paint can monitor on RD0149 reads close to background levels, most of the short-lived airborne radioactivity has decayed away as intended. It was also determined that the ^{7}Be airborne radioactivity is quickly reduced when the 1000 cfm fan is turned on after 4 hours of beam shutoff. Any airborne ^{7}Be would be captured by the high efficiency filters at enclosure air exhaust near MI-10, preventing the ^{7}Be from escaping to the environment. This additional AMS-3 will enable radiation safety personnel to measure the particulate radioactivity before permitting accesses to the enclosure.

Deposition of ^{7}Be in the MiniBoone Enclosure

Over time, ^{7}Be deposited in the enclosure may build up. The relatively long half-life for ^{7}Be (53.3 days) may allow for surface contamination in the enclosure to build up. The short-lived nuclides will routinely decay away in a few hours, however over time the ^{7}Be may build up in the enclosure. If there are no short-lived nuclides on a contamination wipe, it may be difficult to determine the activity of the ^{7}Be without submitting the wipes to RAF for analysis and perform a gamma analysis for ^{7}Be activity levels.

There are two concerns about ^{7}Be deposition in the enclosure: The radiological hazard from exposure to ^{7}Be, and the chemical non-radiological exposure to beryllium in the form of ^{7}Be. For guidance on the non-radiological hazard posed by ^{7}Be, the criterion specified in FESHM 5052.5 was used to evaluate the hazard, and it was determined by calculation that the radiological concerns of ^{7}Be outweigh the non-radiological concerns.

Estimation of Corresponding Count Rate on a Frisker

^{7}Be has a 10% gamma branching ratio. Assume the frisker probe is 1% efficient for 477 keV gammas:

$$(0.10)(0.01)(7x10^7\,nCi)\left(\frac{2.22x10^3\,dpm}{nCi}\right) \approx 1.6x10^8\,cpm$$

The estimated corresponding count rate seen on a frisker at the FESHM beryllium release limit would be extraordinarily high. This estimation shows that at lower levels of ^{7}Be contamination, there is no concern that the levels of beryllium contamination exceed the non-radiological FESHM limits. Indeed, the count rates would be off-scale. The radiological consideration of ^{7}Be outweighs the FESHM non-radiological chemical related release criterion and is the driving factor in responding to ^{7}Be concerns.

Estimates of Count Rate on E140N from ^{7}Be

Data from wipe #14 (021212JF01): On 12/12/02 ^{7}Be 1390 pCi/wipe and ^{24}Na 33.6 pCi/wipe. Assume ^{24}Na decayed away (7 half-lives) on count date 12/17/02. (E140N #5 10/03)

Background ~20 cpm
Net Count rate from wipe #14 assumed from ^{7}Be only ~10 cpm

Or ~ 0.139 nCi/wipe-cpm

$$\frac{7x10^7 nCi/wipe}{0.139 nCi/wipe-cpm} \approx 5x10^8 cpm$$

Data from strip line air filter sample 030123JF01: 9380 pCi/g of ^{7}Be, filter sample was ~1 gram. Net count rate from frisker was 40 cpm. 9380 pCi/40 cpm = 235 pCi/cpm,

Or ~0.235 nCi/cpm

$$\frac{7x10^7 nCi/wipe}{0.235 nCi/wipe-cpm} \approx 3x10^8 cpm$$

Rule of thumb: If we assume a 10% branching ratio for ^{7}Be and a frisker efficiency of 1%, 1 cpm corresponds to approximately 0.45 nCi ^{7}Be. To use this rule of thumb, sufficient time should be allowed for the decay of the short-lived radionuclides. That is, ^{7}Be should be the only radionuclide assumed to be present on the wipe. Empirically it was estimated that 1 cpm on a frisker corresponds to an average of about 0.15 nCi of ^{7}Be, and the efficiency was about 0.03. Therefore the Rule of Thumb is conservative. See Attachment 5.

Additional Surveys and Investigations

Much effort went into the design and construction of the seal between the Target Box and the MI-12B enclosure. It is believed that the wall is sealed as well as possible.

In January 2003, the strip-line service filter in the MI-12 Service Building was replaced, and a sample was submitted that indicated ^{7}Be was present. The air intake plenum was extended so that the air intake was further away from the filter to provide better airflow. This modification was made independent of the ^{7}Be problems, as it was noticed the air intake was too close to the filter. This was a minor modification, and it was not thought that there was any relationship between the air intake of the strip-line cooling and the ^{7}Be problems. The flow rate velometers were replaced in the strip lines to pre-empt electronic failure of the controllers due to radiation damage. Prior to the changeout, the electronic boxes were physically located in the MI-12B enclosure where they would be susceptible to radiation damage. The replacement velometers have longer cables that connect to electronic boxes in the MI-12 Service Building, where the boxes are protected from radiation damage. FESS Engineering confirmed the flow rates were within acceptable tolerances. However this change is not thought to have any cause-effect relationship with the ^{7}Be found.

Also in January 2003, the exhaust plenums where air from the enclosure is exhausted to the environment near MI-10, and where the filters had become laden with ice water and replaced, layers of insulating foam rubber were installed around the plenums. A heater coil to warm the air before it flows through the high efficiency filters was also installed. It was hoped that these measures would alleviate the problem of ice forming in the filters, and it appeared at the time that these measures were successful.

Since the January 2003 shutdown, spot checks with a Bicron Analyst of the cylinder filter for the MI-12 Service Building have been conducted after high intensity run periods for MiniBoone. No elevated counts above background were detected, indicating that no airborne ^{7}Be has infiltrated the MI-12 Service Building.

Periodic contamination wipes of the enclosure during access periods, and checks for evidence of MI-12 Service Building ^{7}Be airborne radioactivity (via the Analyst check of the cylinder filter) were ongoing and documented.

On May 27, 2003, after a long run period, 3 wipes were taken left, center and right on the ledge in front of the target box. This is the same ledge where wipe #14 was taken on 12/12/02. This time 3 wipes were taken and the results indicate that it appears there is more ^{7}Be accumulated on the ledge since December 2002.

On June 3, 2003, the cylinder filter from the MI-12B Enclosure stack monitor was submitted to the RAF for analysis. The results indicated 6,800,000 pCi/g accumulated on the 4.9 gram filter. This filter was in place for 175 days, therefore an assumption can be made that the airborne radioactivity levels were relatively stable throughout the period and an estimate of the ^{7}Be airborne radioactivity concentration can be made. An estimation of the ^{7}Be airborne radioactivity concentration in the MI-12B enclosure is included as Figure 1:

Airborne Concentration of Be-7 in MI-12 Enclosure

The Derived Air Concentration (DAC) for Be-7 is 9 x 10-6 uCi/cm3 for the "WEEKS" lung clearance class
Time of Sampling includes all beam-on and beam-off times
This cylinder filter was in place from 12/10/02 to 6/3/03 (175 days)

Activity	A=	3.30E+07	pCi
Flow Rate	F=	10	L/min
Efficiency	E=	0.9	Filter Efficiency (assumed)

	Time of sampling (hours)	**Estimated uCi/ml Be-7 in MI-12 Enclosure**
175 days	4.20E+03	3.70E-08

Figure 1: Airborne Radioactivity Concentration of ^{7}Be in MI-12B from 12/10/02 to 6/3/03.

The reader is reminded that personnel are unable to be exposed to these concentrations in the enclosure. Nonetheless, it is seen from the results in Figure 1 that the levels were still below the DAC for ^{7}Be.

On June 17, 2003, 16 wipes were taken in the downstream area of the MI-12B enclosure. A separate map of this region has been generated specifically for these wipes. All of the wipes except for one indicated low levels of contamination on the floor region in front of the target box in MI-12B. These wipes were not analyzed for ^{7}Be content; however future wipes may be submitted to RAF for ^{7}Be analysis. 16 fixed locations have been marked out in the enclosure that corresponds to locations indicated on this map. Wipe surveys will be conducted periodically at these fixed locations to track how the ^{7}Be contamination levels accumulate over time. It is understood that the act of taking wipes at a fixed location will in effect clean that particular spot, thus reducing the actual accumulation over time. Other caveats include slight differences in wipe taking techniques. However for qualitative determinations of the ^{7}Be build-up in the region these caveats are regarded as minor points.

On June 3, 2003, the MI-12 Service Bldg stack monitor cylinder filter was submitted to the RAF for analysis. 286 pCi/g of 7Be were reported. This amount of ^{7}Be is considered negligible.

On July 2, 2003, regular air conditioner filters from the MI-12 Service building were sampled for 7Be. 5,910 pCi/g and 7,010 pCi/g were reported. Note that these filters had been in place for several months. These levels of accumulation are considered negligible.

On July 9, 2003, a meeting with Bill Markel was held with Roger Zimmermann and Gary Lauten. It was determined at this meeting that the interface between the strip lines and the horn was on the order of a few square inches at most, so that it appears to be unlikely that a significant amount of air communication exists between the target box air and the enclosure air. By design, the air circulating in the Target Box region of MiniBoone is intended to cool the MiniBoone Horn and strip-lines. There is a physical barrier between the Target Box and the MI-12B enclosure, consisting of moveable doors that close up around the beamline. The air flow over the two strip-lines is designed to cool the strip-lines and provide combined 100 cfm airflow to the enclosure. Each strip-line starts in the MI-12 Service Building and extends down into the MI-12B enclosure, and then they connect to the MiniBoone horn. The horn protrudes out of the target box and there are shutters that close up around the sides of the horn to seal the air in the target box. There are baffles that re-direct the 100 cfm airflow into the MI-12B enclosure, and there is a small air gap around the strip line connections to the horn that are on the order of a few square centimeters (Personal communication with William Markel, July 9, 2003).

In August 2003, two special filter boxes were constructed containing an inner high efficiency filter and an outer one. These were mounted on the two strip line exhausts in the MI-12B enclosure. This test was done to determine whether the source of the ^{7}Be was from the target box, back washing into the strip line ducts and into the enclosure. If the test was positive, the inner filter would have captured airborne ^{7}Be emanating from the strip line exhaust, and none on the outer filter. The results of this test indicated that the strip line ducts were not the likely source of ^{7}Be, as there was no significant difference in the ^{7}Be content on the inner and outer filters.

Also in August, two small test filter housings were attached to the two open vents on the target cooling RAW system. The purpose of this test was to determine if any ^{7}Be was emanating from the target cooling RAW system. The results indicated that the amount of ^{7}Be was insignificant, thus it was unlikely that the RAW system could be the source of the ^{7}Be.

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The target cooling system was investigated extensively to determine if it could be the source of the ^{7}Be. Dr. Gerry Garvey of LANL, a physicist familiar with the system, assisted radiation safety personnel in assessing the integrity of the system. Mechanical support personnel conducted several variations of leak tests, and it was determined that the piping downstream of the filter (in the enclosure between the filter and the target box) did indeed have small leaks. In fact every joint was found to leak slightly. Modifications were made to these joints to seal them better. Dr. Garvey recommended "non-organic" (i.e. metal to metal) connectors, however these types of connectors were not readily available within the time frame of the shutdown so "Locktite" connectors were used instead. The target cooling system and the floor area surrounding the target cooling filter housing were cleaned using masolin™ cloth and wet sweeping. A set of 5 baseline wipes were taken to track any increase of ^{7}Be in this area in the future. It is hoped that the modifications made will reduce the ^{7}Be levels produced in the enclosure, and that the existing ^{7}Be will physically decay over time. Periodic surveys will continue to assess the ^{7}Be levels in the enclosures.

Conclusions:

The radiological hazards posed by the levels of tritium and ^{7}Be found during this investigation were considered minimal.

With respect to the non-radiological hazard of ^{7}Be, the FESHM release criterion count rate on a

100-cm^2 wipe, as seen on a frisker, is estimated to be extraordinarily high at ~10^8 cpm. The radiological contamination limits are realized at lower levels of ^7Be than the non-radiological FESHM limit. The limiting criterion is therefore the FRCM radiological contamination limits.

No physical evidence was observed in January 2003 that the exhaust filter integrity where the enclosure air is released to the environment (near MI-10) had been compromised. In addition, no counts above background were observed on the two wipes taken on the 100 cfm exhaust ports at MI-10 downstream of the filter.

The ^7Be concentration numbers seen for the cylinder filters are the results seen after several days of continuous airflow at 10 Liters/min. Over time the airborne ^7Be would collect on the filters and build up. Even if a worst-case scenario of all the ^7Be was produced in the day before the air monitor cylinder filters were removed, the estimated airborne concentration in the enclosure and the MI-12 Service Building are below the Derived Air Concentration for ^7Be (9×10^{-6} $\mu Ci/cm^3$). This scenario is however deemed unlikely. It is more likely that the ^7Be was being produced over time as part of the normal operation of the MiniBoone beamline since there was no indication of abnormal beam losses or other unexpected events.

At this writing, this investigation is considered on-going. It is hoped that the modifications and adjustments made to the target cooling system will be successful in reducing the rate of ^7Be production in the tunnel. This paper will be updated in the future as further investigations and results dictate.

Acknowledgements

Many persons contributed their insight, time, and effort to this on-going investigation, especially Gerry Garvey, Vladimir Sidorov, Robert Reilly, Fred Krueger, and Bess Kershisnik.

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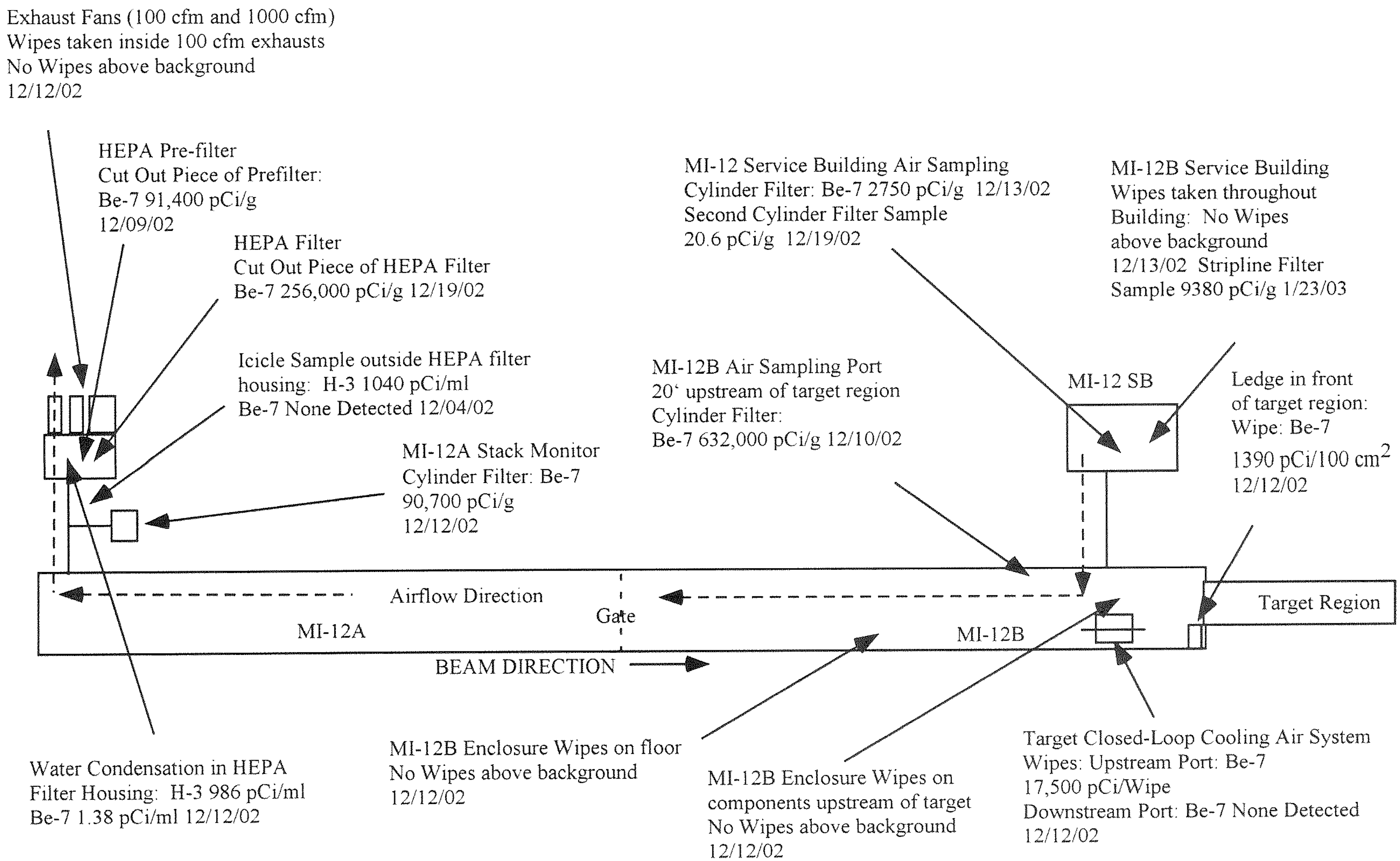
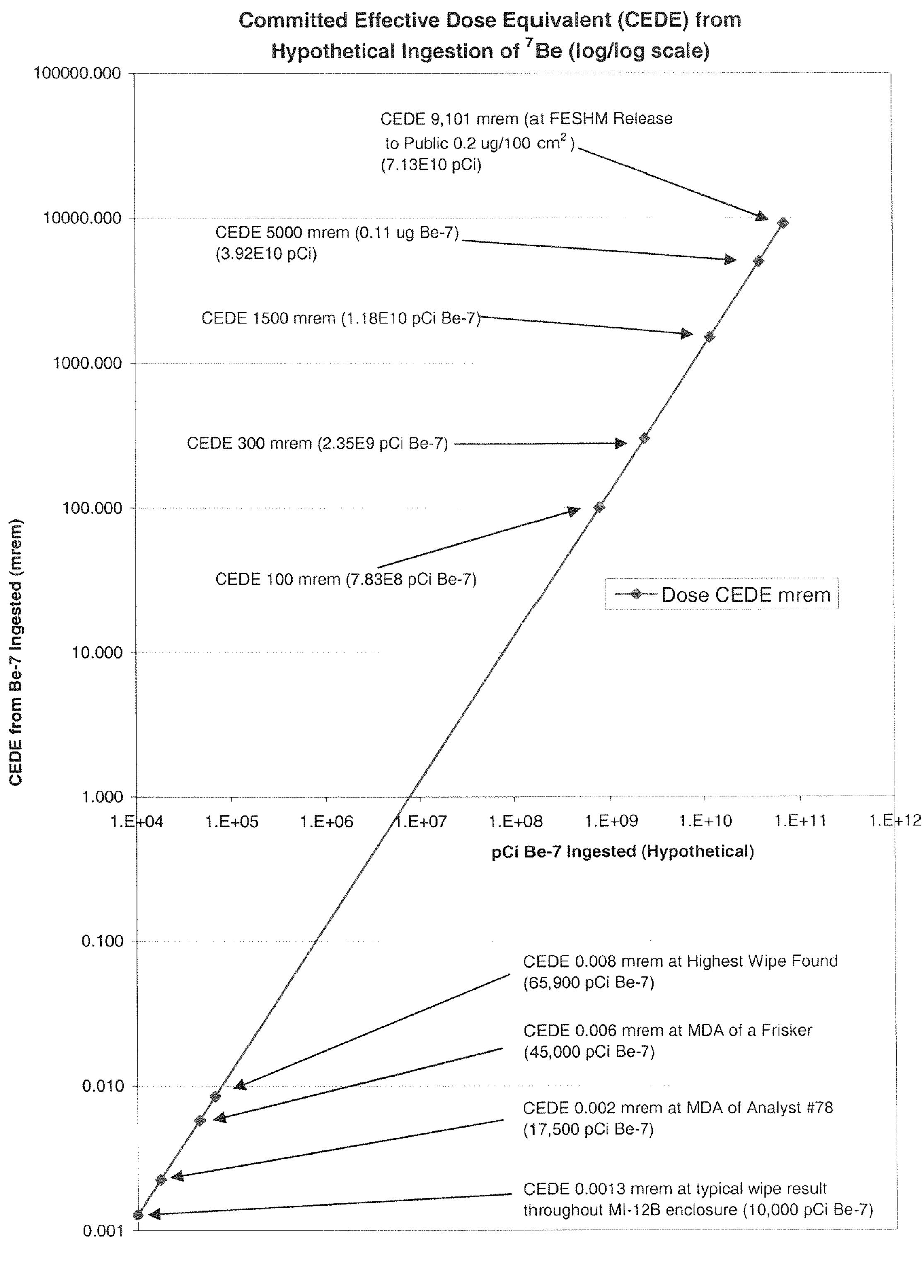
MiniBoone Beryllium-7 Investigation
December, 2002 - January 2003

AS OF January 23, 2003



Attachment No. 1



Attachment No. 2

Airborne Concentration of Be-7 in MI-12 Enclosure

The Derived Air Concentration (DAC) for 7Be is 9 x 10-6 uCi/cm3 for the "WEEKS" lung clearance class

Time of Sampling includes all beam-on and beam-off time

Activity	A=	3.10E+06	pCi
Flow Rate	F=	10	L/min
Efficiency	E=	0.9	Filter Efficiency (assumed)

	Time of sampling (hours)	**Estimated uCi/ml Be-7 in MI-12 Enclosure**
1 day	24	2.41E-07
	48	1.21E-07
	72	8.13E-08
	96	6.14E-08
	120	4.94E-08
	144	4.14E-08
1 week	168	3.58E-08
	192	3.15E-08
	216	2.82E-08
	240	2.55E-08
	264	2.33E-08
	288	2.15E-08
	312	2.00E-08
2 weeks	336	1.87E-08
	360	1.76E-08
	384	1.66E-08
	408	1.57E-08
	432	1.49E-08
	456	1.42E-08
	480	1.36E-08
3 weeks	504	1.30E-08
	528	1.25E-08
	552	1.20E-08
	576	1.16E-08
	600	1.12E-08
	624	1.08E-08
	648	1.05E-08
4 weeks	672	1.02E-08
	696	9.91E-09
	720	9.64E-09
	744	9.38E-09
	768	9.14E-09
	792	8.92E-09
	816	8.71E-09
5 weeks	840	8.51E-09

Attachment No. 3

Airborne Concentration of Be-7 in MI-12 Service Building

The Derived Air Concentration (DAC) for 7Be is 9 x 10-6 uCi/cm3 for the "WEEKS" lung clearance class

Time of Sampling includes all beam-on and beam-off time

Activity	A=	2.75E+03	pCi
Flow Rate	F=	10	L/min
Efficiency	E=	0.9	Filter Efficiency (assumed)

	Time of sampling (hours)	Estimated uCi/ml Be-7 in MI-12 SB
1 day	24	2.14E-10
	48	1.07E-10
	72	7.21E-11
	96	5.44E-11
	120	4.38E-11
	144	3.68E-11
1 week	168	3.17E-11
	192	2.79E-11
	216	2.50E-11
	240	2.26E-11
	264	2.07E-11
	288	1.91E-11
	312	1.77E-11
2 weeks	336	1.66E-11
	360	1.56E-11
	384	1.47E-11
	408	1.39E-11
	432	1.32E-11
	456	1.26E-11
	480	1.21E-11
3 weeks	504	1.16E-11
	528	1.11E-11
	552	1.07E-11
	576	1.03E-11
	600	9.95E-12
	624	9.62E-12
	648	9.32E-12
4 weeks	672	9.05E-12
	696	8.79E-12
	720	8.55E-12
	744	8.32E-12
	768	8.11E-12
	792	7.91E-12
	816	7.73E-12
5 weeks	840	7.55E-12

Attachment No. 4

Frisker Count Rates on Several Wipes Taken in MI-12B

Sample ID
Frisker #23 030711PS04
Counted July 23, 2003
bkg=20 cpm
CCPM= "Corrected (net) Counts per Minute"

Wipe #	Frisker GCPM	CCPM	RAF Be-7 pCi	pCi/ccpm
1	20	0	0	
2	20	0	0	
3	20	0	1790	
4	100	80	13700	171.25
5	60	40	7420	185.50
6	120	100	10900	109.00
7	100	80	10800	135.00
8	70	50	8790	175.80
9	70	50	4990	99.80
10	50	30	5420	180.67
11	80	60	10800	180.00
12	100	80	11700	146.25
13	80	60	14800	246.67
14	70	50	8470	169.40
15	100	80	8810	110.13
16	100	80	11200	140.00
17	80	60	9730	162.17
18	100	80	14800	185.00
19	140	120	16100	134.17
20	100	80	11000	137.50
21	60	40	7740	193.50
22	150	130	16800	129.23
23	20	0	1370	
24	140	120	15700	130.83
25	100	80	15200	190.00
26	20	0	1480	
27	120	100	17000	170.00
28	20	0	1190	
29	60	40	1690	42.25
30	60	40	12900	322.5
31	60	40	5520	138
32	20	0	276	
33	40	20	374	18.7
34	20	0	851	

Average= 153.97 pCi/ccpm

or 0.15 nCi/ccpm Be-7

Frisker Efficiency ~ 0.03

Attachment No. 5